Influence of solar radiation on the productivity and nutritive value of herbage of cool-season species of an understorey sward in a mature conifer woodland

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Abstract

Silvopastoral systems in the Appalachian region of the USA could increase the carrying capacity of livestock and contribute to a reliable supply of high-quality herbage. In 2000, 2001 and 2002, the influence of solar radiation [0·20, 0·50 or 0·80 of maximum solar radiation (MSR); treatments 20-, 50- and 80-MSR respectively] on the productivity and nutritive value of a mixture of sown grasses and legumes established under a mature stand of conifers was investigated. Yields of dry matter (DM), crude protein (CP), total non-structural carbohydrates (TNC) and total digestible nutrients (TDN) were greater for the 80-MSR treatment except in 2000 when DM yield did not differ. As a proportion of the sward, introduced species (*Dactylis glomerata* L., *Trifolium repens* L., and *Lolium perenne* L.) increased over time for the MSR-80 treatment, corresponding with a decrease in the proportion of bare area and of non-introduced species. CP concentration of herbage was 207 g kg^{-1} DM or greater across treatments and years with higher concentrations on the 20- and 50-MSR treatments. Herbage from the 80-MSR treatment had a greater concentration of TNC than that of the 20- and 50-MSR treatments. Estimated concentration of TDN was similar for all treatments in 2000 and greater for the 80-MSR treatment than the other two treatments in 2001 and 2002. High CP concentrations in herbage, as a result of appropriate thinning of trees in an Appalachian silvopastoral systems, could be utilized as a protein supplement to herbage with low CP and higher fibre concentrations.

Keywords: silvopastoral systems, nutritive value of herbage, dry matter yield of herbage, swards, conifers

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Introduction

Silvopastoral systems in maritime temperate regions, such as New Zealand and the UK, generally involve the introduction of trees to pasture, increasing the supply of wood and tree products. In much of the USA, silvopastoral systems involve the inclusion of swards as understorey crops in tree plantations designed to expand the temporal and spatial boundaries of herbage production, and increase efficiency of land-use and livestock production. Open pasture in the Appalachian region of the USA is relatively scarce, and woodland is abundant.

The Appalachian region has many small-scale, <100 ha, pasture-based livestock farms that are a mosaic of open pasture and woodland. The wooded area is often not used in the livestock production component of the farming operation nor does it contribute to farm income largely because of topographical and economic constraints. A common problem with pastures throughout much of the Appalachian region is that a relative decline in forage quality and quantity occurs during summer when weather conditions and plant development influence herbage production. High temperatures and lack of rainfall in mid-summer cause herbage growth to slow or cease. Plants reach morphological maturity and senescence results in decreased crude protein (CP) and increased structural carbohydrate concentrations of herbage, thus reducing its nutritive value. The moderating influence of a tree canopy might sustain understorey growth (Sibbald, 1999). Silvopastoral systems in the Appalachian region mainly require thinning of wooded areas to an appropriate level to allow sustainable forage growth rather than by planting trees in open pasture. Topographical and economic constraints demand establishment practices which minimize the need for heavy equipment, keep soil disturbance to a minimum and are cost-effective.

Benefits of silvopastoral systems are numerous and have been summarized by Mosquera-Losada *et al.* (2005) Extension of the growing season of herbage via protection of swards from environmental extremes and overall increases in forage production have been shown by Sibbald (1999). Kephart and Buxton (1993) found that shade tended to decrease secondary cell-wall development and proposed that morphological changes in herbage grown under reduced light, e.g. under a tree canopy or in areas with prolonged cloudiness, would very likely increase the nutritive value of herbage, estimated in terms of its CP concentration. Peri *et al.* (2007) also found increased CP concentrations with increasing shade for herbage of *Dactylis glomerata*.

Conversely, low radiation levels have been shown to reduce forage production and nutritive value. Research in Scotland, UK (Sibbald *et al.*, 1994) showed that herbage production decreased with increased shading (or attenuation of full sunlight) when precipitation and temperature favour herbage growth. Belesky (2005) and Peri *et al.* (2007) found that herbage plants grown in areas with lower light levels were smaller, had fewer numbers of tillers and produced less dry matter (DM) compared with treatments with higher levels of radiation. Shade-grown grasses of cool-temperate origin increase allocation of N to leaves to maximize light acquisition. Lin *et al.* (2001) found that, in general, acid–detergent fibre (ADF) concentration was either unaffected or increased because of shading. The high nitrate concentrations, along with depressed levels of total non-structural carbohydrates (TNC), found in shade-grown herbage (Deinum *et al.*, 1968; Chiavarella *et al.*, 2000) could compromise nutritive value. Concentration of TNC in herbage has been positively associated with improved dietary protein utilization in the rumen, and increased selection and intake by grazers (Chiavarella *et al.*, 2000; Mayland *et al.*, 2000). High levels of N in herbage have also been associated with off-flavours in meat from pasture-raised beef cattle (Lane and Fraser, 1999).

It was hypothesized that silvopastoral systems, which are low input systems with regards to establishment and maintenance, could increase carrying capacity and may help to ensure a reliable supply of high quality herbage, a major requirement of successful livestock production systems. The objective was to evaluate the influence of solar radiation on the production of DM and the nutritive value of a mixture of sown grasses and legumes established by low input means under a stand of conifers (mixed species). The goal is to develop management strategies to optimize the productivity of small farms in the Appalachian region of the eastern USA and in similar hill-land environments.

Materials and methods

Site and treatments

An existing 35-year-old 17-m tall mixed-species stand of conifers on a west-facing 0·58-ha site in southern West Virginia (37° 46′N, 81° 00′W, 854 m.a.s.l.) was utilized as the experimental site. The soil of the experimental site was classified as Gilpin (fine loamy, mixed, semi-active, mesic Typic Hapludult). The site was dominated by white pine (*Pinus strobus* L.) and red spruce (*Picea rubens* Sarg.) with sparse numbers of pitch pine (*P. rigida* Mill.) and short-leaf pine (*P. echinata* Mill.). The understorey consisted primarily of a 1–2 cm leaf litter layer, and sparse, evenly distributed patches of herbaceous species. Trees were originally planted at approximately 1·5 m centres and had been unmanaged since planting. Tree senescence over the years had left areas of the stand thinned, resulting in variable shading throughout because of the tree canopy. The area was, therefore, partitioned into 68, 9 m × 9 m plots to create a grid for classification and reference purposes. For individual plot classification purposes, photosynthetically active radiation (PAR) was measured during midday for all plots using a 1-m Sunfleck Ceptometer PAR meter (Decagon Devices, Pullman, WA, USA). Five equidistant measurements (including centre of the plot and two measurements on both sides with 1·75 m spacing) were recorded along the north–south centre line of each plot for the whole site followed by a second transect, collecting five additional measurements along the east–west centre line of each block for the whole site. Corresponding measurements of PAR were made 50 m outside the conifer stand in an open field for reference purposes. About 2 h were required to complete measurements on a given day. The ten values were averaged for each plot. While measurements were made on several dates, only data from Julian day 253 during 1999 were collected without any clouds forming and was used for evaluating plot maximum solar radiation (MSR). Based on this data obtained on 10 September1999, four plots each were selected representing 0·20, 0·50 and 0·80 MSR (20-, 50-, 80-MSR) to assess nutritive value, DM production and botanical composition. Treatment plots were randomly distributed within the stand with MSR values being the result of greater or lesser tree canopy density within plots. Experimental design was completely randomized with four replicates per treatment. Herbage samples for assessment of botanical compositions were collected via four sub-samples within each replicate plot.

Weather data for the 3 years of the study along with 30-year means are presented in Figure 1.

Establishment of sward

Prior to establishment of the sward, all dead tree material was removed from the ground and soil samples taken from each plot for nutrient and pH assessment. Individual plots were then treated with dolomitic lime to achieve a target pH of 6·2. Phosphorus (as P_2O_5) was

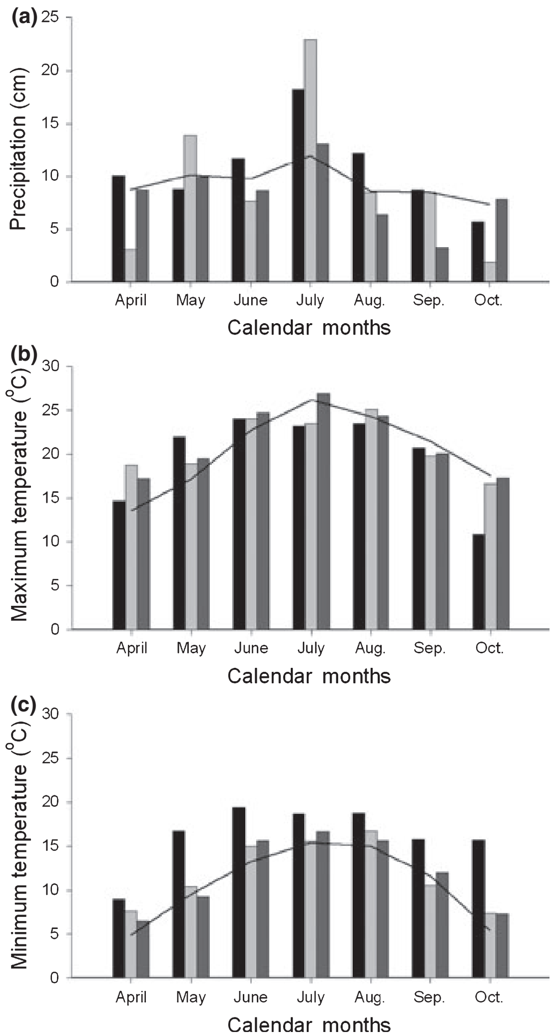

Figure 1 Monthly (a) precipitation (cm), (b) minimum and (c) maximum temperatures (°C) in 2000 (■), 2001 (□) and 2002 (■), and 30-year means (–) for experimental site.

applied to achieve a mean of 34 kg ha^{-1} Bray P, an estimate of plant available P for acid soils (Bray and Kurtz, 1945), in each plot. During the establishment year, starter fertilizer applications of 112 kg K ha^{-1} and 34 kg N ha^{-1} were applied over the entire site on 19 March and 3 May, 1999. Between 23 March and 1 April, 1999, forty-six mature crossbred wether sheep (approximate live weight, 75 kg) were fed baled, cool-season forage hay and shelled corn (*Zea mays* L.) scattered at random across the site to accelerate disruption of surface leaf litter. The site was sown on 2 April, 1999 using a hand-operated cyclone seeder to apply 8·4 kg ha^{-1} orchardgrass (*D. glomerata* L.; variety Benchmark, 6·2 kg ha^{-1} white clover (*Trifolium repens* L., cultivar Huia) and 4·3 kg ha^{-1} each of two varieties of perennial ryegrass (*Lolium perenne* L; varieties Elf and Seville). Shelled corn was then broadcast and sheep returned to tread in the seed. During the remainder of the establishment season, the entire site (0·58 ha) was grazed twice by eighteen mature crossbred wether sheep to control weeds and the developing sward. The area was reseeded on 13 August, and eighteen sheep were used to tread in the seed as before. No fertilizer was applied in 2000.

Sward and grazing management

No fertilizer was applied in 2000. The entire site received 34 kg N ha^{-1} on Julian day 149 in 2001 and 28 kg N ha^{-1} on day 116 of 2002.

Grazing throughout the experiment was for herbage canopy management only with no data on sheep production being collected. Both mature sheep and lambs were used as grazers. The entire 0·58-ha site was grazed as one event and grazing events on average were 6 days in length. Events began on 18 April, 11 May and 9 May in 2000, 2001 and 2002, respectively, when average canopy height of herbage reached 20 cm. Grazing events for the remainder of the grazing season were initiated when mean canopy height of herbage reached approximately 20 cm. During each grazing event, the aim was to achieve a similar residue sward height of 4 cm. Grazing events, and thus sampling dates for the measurement of nutritional value and DM production, were relative to the yearly grazing season. The final sampling dates were 6 September, 1 October and 9 August for the grazing seasons in 2000, 2001 and 2002 respectively. Total grazing events for each grazing season were 6, 5 and 3 for years 2000, 2001 and 2002 respectively.

Measurements

Before each grazing event, herbage samples for measurement of nutritive value and DM production estimates were collected from four, 0·08-m^2 quadrats clipped to 4 cm above ground level in each plot. Sampling sites within plots were selected based on visual evaluation of DM availability of herbage of introduced species with maximum herbage mass being the major factor on choice of the sampling site. Samples were dried at 60°C in a forced-draught oven, and weighed to measure herbage mass of DM. Samples were then ground through a 1-mm mesh stainless steel screen prior to analyses of nutritive value. Measurements of nutritive value and DM yield are presented as means of the grazing events for the grazing season within year.

Samples were analysed for concentrations of total nitrogen (Carlo-Erba EA 1108 CNS elemental analyzer;

Fisons Instruments, Beverly, MA, USA), ADF (Goering and Van Soest, 1970; as modified by Van Soest *et al.*, 1991), total TNC (Smith, 1981; as modified by Denison *et al.*, 1990) and nitrate (Alloush *et al.*, 2003; Dionex Application Note # 135; Dionex DX 500 I.C. ion chromatography (Dionex Corporation, Sunnyvale, CA, USA).

Computations for nutritive value included CP concentration as total N concentration × 6·25 and metabolizable energy (ME) concentration of herbage as ME (MJ kg^{-1} DM) = 15·3−(0·0153ADF) (g kg^{-1} DM) (MAFF/ADAS, 1987). Total digestible nutrients (TDN) concentrations were calculated from ME concentrations (NRC, 1996).

Botanical composition was determined each year in mid-May, mid-July and late-September by the point-intercept method (Warren-Wilson, 1959), taking four 25-point locations per plot. Measurements were taken from the same locations during the grazing season and across years. Categories were orchardgrass, ryegrass, white clover, velvetgrass, fescue, other grasses, weeds, rock and bare ground. For statistical analysis and presentation, botanical identifications were classified as: (i) target species: orchardgrass, ryegrass and white clover; (ii) non-introduced species: velvetgrass, fescue, other grasses and weeds; (iii) bare ground and (iv) rock.

Statistical analyses

Data were analysed as a completely randomized design with repeated measures over time, with four replicates per treatment and four sub-samples per replicate. Solar radiation treatments were modelled as a fixed effect and replication as random. The GROUP option for solar radiation was used in the random statement to specify that the intercept and slope effect of one light environment is independent of the intercept and slope of the other light environments but correlated within each light environment, using SAS MIXED procedures in SAS (Littell *et al.*, 1996). Degrees of freedom of the denominator were calculated using the Satterthwaite option, and were used to test mean square estimates, standard errors and *t*-ratios for multiple error terms. Years were analysed separately where the chi-square test for homogeneity of variance failed ($P \geq 0{\cdot}05$) in the model for light. Effects were considered significant at $P \leq 0{\cdot}05$.

Results and discussion

Dry matter yield

Samples for DM yield estimates and nutritive value were collected when average sward height reached approximately 20 cm. Average sward height was used as the determining factor for sampling times to ensure ample herbage accumulation prior to beginning each grazing interval. Variation in herbage growth rate among years, and differences in the length of the growing season attributable to environmental factors resulted in different numbers of harvests in different years as well as different lengths of time between samplings. However, given that samples for treatment comparisons were collected at the same time, variability because of these factors should be relative between treatments. Sampling sites were selected (based on visual evaluation) to maximize collection of the target sown species. This approach provided an estimate of the potential yield of those species within a site and was chosen primarily because of sward establishment procedures. Establishment of target species without a traditionally managed seedbed resulted in a highly variable sward composition. Botanical composition data (discussed later) were collected to evaluate response of target species in competition with indigenous species and their ability to reduce bare ground through increased ground cover. Young target species had to compete with established indigenous species for space and nutrients. As stress factors (including lack of adequate solar radiation and competition from other plant species) influence herbage establishment, selection for maximized yield removed bias towards the greater MSR treatments because of responses associated with the greater availability of solar energy.

Average data on DM yield and botanical composition for each year are presented in Figure 2. In 2000, the only difference between treatments was in the DM yield of the 80-MSR treatment which was greater ($P < 0{\cdot}05$) than for the 50-MSR treatment. In both 2001 and 2002, DM yield was greater ($P < 0{\cdot}05$) for the 80-MSR treatment while the DM yields of the 20- and 50-MSR treatments did not differ. DM production was 2·0 times greater in 2001 and 1·62 greater in 2002 for the 80-MSR treatment compared with the 20- and 50-MSR treatments. Sibbald *et al.* (1994) in Scotland, UK found that herbage production decreased with increased shading when precipitation and temperature did not limit herbage growth. Lin *et al.* (1999) also showed a reduction of yield because of increased shade for orchardgrass, ryegrass and white clover (the same species as introduced in this study). This is also in agreement with Peri *et al.* (2007). During 2002, precipitation was below average and temperatures were above average, and increased shading reduced DM yield. On an adjacent study site during 2002 (data not shown), herbage production from an open site was compared with that from a hardwood silvopasture. Sites were treated similarly in regards to fertilizer application and DM removal via grazing. Hardwood silvopasture was also thinned to produce approximately the same density as

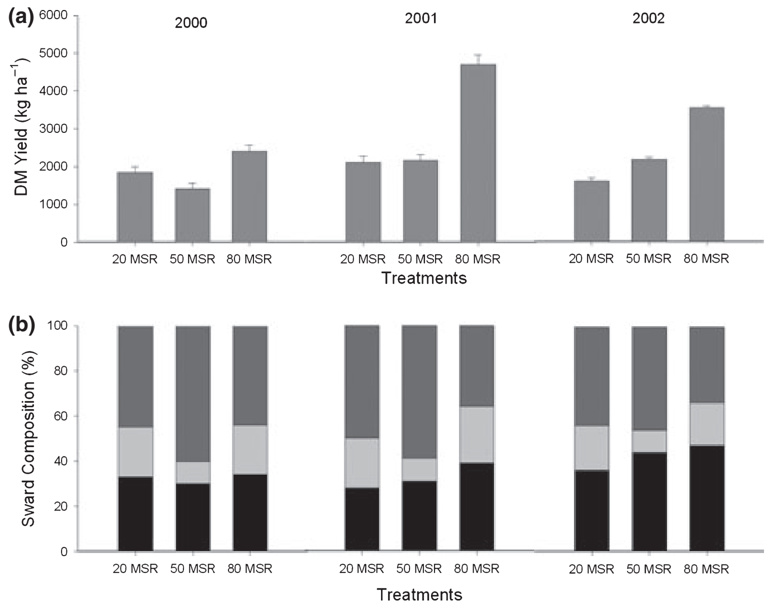

Figure 2 (a) Yield of dry matter of herbage (kg ha^{-1}) and (b) sward composition (black, target species; light grey, other species; and intermediate grey, rock and bare ground) for treatments: 0·80 of maximum solar radiation (MSR-80), 0·50 of maximum solar radiation (MSR-50) and 0·20 of maximum solar radiation (MSR-20) in 2000, 2001 and 2002. Values are means and standard errors of twelve replicates.

the 80-MSR treatment. The DM yield of herbage from the hardwood silvopasture was similar to that of the 80-MSR treatment. Over the same grazing period, the yield of the herbage from the hardwood silvopasture was 3247 kg DM ha^{-1}, which is similar to the yield of the 80-MSR treatment (3545 kg DM ha^{-1}) while the open pasture yielded 8505 kg DM ha^{-1}. Results indicate no advantage for silvopasture with regards to DM yield during periods of low (2002) or excess (2001) rainfall. However, DM yield for the 80-MSR treatment indicates silvopasture is a viable option within the Appalachian region to increase overall farm herbage production by expanding the pasture area into woodlands. Expansion of grazing area through silvopasture establishment increases overall herbage production, and can improve woodlot management and farm landscapes.

Botanical composition

The botanical composition of the swards is presented in Figure 2. In 2000, the MSR treatments did not influence the proportion of introduced species (i.e. orchardgrass, ryegrass and white clover). In the 20- and 50-MSR treatments, grass species were 0·90 of the introduced species. On the 80-MSR treatment, they were 0·86 of the introduced species (data not shown). In 2001, the composition of target species did not differ between the 20- and 50-MSR treatments (grasses accounted for 0·85 and 0·96 respectively of the total; data not shown). However, the proportion of introduced species on treatment 80-MSR was greater ($P < 0{\cdot}05$) than on treatment 20-MSR and tended ($P = 0{\cdot}08$) to be greater than on treatment 50-MSR (treatment 80-MSR contained approximately equal proportions of target grass and clover species; data not shown). In 2002, treatments 50-MSR and 80-MSR had a higher ($P < 0{\cdot}05$) proportion of introduced species than treatment 20-MSR (clover accounted for 0·05, 0·18 and 0·11 of the target species respectively, data not shown). Non-introduced species (fescue, velvetgrass, other grasses and weeds) were lowest ($P < 0{\cdot}05$) on the 50-MSR treatment and did not differ ($P > 0{\cdot}05$) between the 20-MSR and 80-MSR treatments throughout the study. In general, introduced species increased as a proportion of the sward within treatment 80-MSR over the study period (0·34, 0·39 and 0·47, for 2000, 2001 and 2002 respectively). The increase in introduced (sown) species corresponded with a decrease in bare ground and non-introduced species.

Nutritive value

Concentrations of crude protein and nitrate in herbage

Solar radiation influenced ($P < 0{\cdot}01$) CP concentrations in each year (Table 1). In the 3 years of the study, the concentration of CP in herbage was greater for the 20- and 50-MSR treatments than for the 80-MSR treatment. The concentration of CP in herbage on the 50-MSR treatment was greater than that on the 20-MSR treatment in 2000 and 2001, and similar in 2002. The higher CP concentration in herbage was associated with greater shade which is in agreement with previous research (Deinum *et al.*, 1968; Kephart and Buxton, 1993; Lin *et al.*, 2001; Peri *et al.*, 2007). Specifically, Lin *et al.* (2001) showed that the CP

Table 1 Mean concentrations of crude protein (CP), total non-structural carbohydrates (TNC), nitrate (NO_3) and total digestible nutrient (TDN) and ratio of TDN : CP concentrations of herbage for treatments: 0·80 of maximum solar radiation (MSR-80), 0·50 of maximum solar radiation (MSR-50) and 0·20 of maximum solar radiation (MSR-20).

Treatment	2000 CP (g kg^{-1} DM)	2000 NO_3 (g kg^{-1} DM)	2000 TNC (g kg^{-1} DM)	2000 TDN (g kg^{-1} DM)	2000 TDN : CP	2001 CP (g kg^{-1} DM)	2001 NO_3 (g kg^{-1} DM)	2001 TNC (g kg^{-1} DM)	2001 TDN (g kg^{-1} DM)	2001 TDN : CP	2002 CP (g kg^{-1} DM)	2002 NO_3 (g kg^{-1} DM)	2002 TNC (g kg^{-1} DM)	2002 TDN (g kg^{-1} DM)	2002 TDN : CP
MSR-20	256·8^{b}	10·9^{b}	27·7^{b}	638·6	2·53^{b}	226·5^{b}	7·6^{a}	64·3^{b}	628·2^{b}	2·85^{b}	244·2^{a}	9·0^{b}	45·2^{b}	670·8^{b}	2·83^{b}
s.e. of mean	0·53	1·58	0·17	0·73	0·05	0·48	1·70	0·41	0·58	0·08	0·59	1·12	0·27	0·37	0·09
MSR-50	270·6^{a}	14·8^{a}	30·1^{b}	636·1	2·36^{b}	248·8^{a}	11·7^{a}	65·8^{b}	631·6^{b}	2·57^{b}	247·9^{a}	13·4^{a}	44·8^{b}	666·0^{b}	2·74^{b}
s.e. of mean	0·31	1·21	0·17	0·79	0·06	0·34	1·78	0·32	0·48	0·08	0·46	1·83	0·20	0·25	0·08
MSR-80	240·7^{c}	5·3^{c}	53·3^{a}	644·0	2·74^{a}	207·2^{c}	2·3^{b}	96·1^{a}	659·7^{a}	3·25^{a}	218·5^{b}	3·8^{c}	68·1^{a}	685·8^{a}	3·22^{a}
s.e. of mean	0·53	1·12	0·33	0·84	0·08	0·45	0·60	0·44	0·55	0·12	0·53	0·81	0·08	0·34	0·08

Column means with different letter superscripts are significantly different at $P < 0·05$.

concentration of orchardgrass and ryegrass increased progressively with increasing shade while no change was evident for white clover. Orchardgrass and ryegrass were the predominant species within 20- and 50-MSR treatments across all years. Across all treatments and years, the CP concentration in herbage exceeds the requirements of growing, finishing and lactating beef cattle (NRC, 1996).

The nitrate concentration in herbage was also influenced ($P < 0·001$) by solar radiation treatment (Table 1) with treatment 80-MSR having the lowest concentration. Nitrate concentration was generally highest in the herbage on the 50-MSR treatment. Mean nitrate concentration in herbage on the 80-MSR treatment indicates that the herbage would be considered safe for livestock to ingest in all years. On the 20- and 50-MSR treatments, nitrate concentrations ranged from 7·6 g kg^{-1} DM for the 20-MSR treatment in 2001 to 14·8 g kg^{-1} DM for treatment 50-MSR in 2000. Essig *et al.* (1988) indicated feeds containing 6·6–13·3 g kg^{-1} DM should be limited to 0·50 of the total DM intake, while that containing 13·3–19·9 g kg^{-1} DM should be limited to 0·25 of the DM intake. Results show caution should be taken under extreme shading conditions. While there were no problems with sheep grazing herbage in this study, sheep had access to all herbage within the study site during grazing events. This would allow them to limit intake on their own. We noted that the sheep tended to prefer herbage from the less shaded areas compared with areas with more shade.

Concentrations of carbohydrate components in herbage

The concentration of ADF in herbage is indicative of herbage quality with lower concentrations being associated with higher quality. The solar radiation treatments influenced ($P < 0·01$) ADF concentrations in 2001 and 2002 (data not shown; ADF concentration of herbage can be calculated from TDN concentration if desired, see Materials and methods). Concentrations of ADF were lower on treatment 80-MSR than on treatments 20- and 50-MSR. Lin *et al.* (2001) reported that, in general, ADF concentrations were either increased or unaffected by shading. Conversely, Kephart and Buxton (1993) found that shade tended to decrease secondary cell-wall development. Difference in findings may be related to light quality, the manner in which forages were managed and the plant species involved. Increased far-red light relative to red light occurring under shading conditions was associated with a shift in allocation of carbohydrates to stem elongation (Ballare *et al.*, 1990). Shading in this experiment was caused by conifer trees at the site, while Lin *et al.* (2001) and Kephart and Buxton (1993) imposed artificial shade.

Concentration of TNC in herbage was influenced ($P < 0{\cdot}001$) by solar radiation treatments in all years (Table 1). Total non-structural carbohydrate concentration in herbage was greatest on the 80-MSR treatment in all 3 years, with TNC concentrations being similar in herbage from the 20- and 50-MSR treatments. Concentrations were lowest in 2000 (53·3, 27·7 and 30·1 g kg^{-1} DM for treatments 80-, 50- and 20-MSR respectively); highest during 2001 (96·1, 64·3 and 65·8 g kg^{-1} DM for treatments 80-, 50- and 20-MSR respectively) and intermediate in 2002 (68·1, 45·2 and 44·8 g kg^{-1} DM for treatments 80-, 50- and 20-MSR respectively). Moore and Hatfield (1994) reported a range for cool-season grasses of 60–180 and 30–160 g kg^{-1} for temperate legumes. Concentration of TNC in herbage were clearly low at all times except for treatment 80-MSR in 2001 (96·1 g kg^{-1} DM). Oddly, white clover content was higher in the 80-MSR treatment than the 20- and 50-MSR treatments in 2001 (data not shown). In 2002, the concentration on the 80-MSR treatment (68·1 g kg^{-1}DM) was similar to that in herbage collected on an adjacent study site (data not presented) from open pasture and a hardwood silvopasture. Intake of herbage is known to be influenced by its concentration of TNC (Mayland *et al.*, 2000), and Chiavarella *et al.* (2000) suggested that a lower concentration of TNC in herbage, caused by shading, could compromise its nutritive value. Clearly, the concentration of TNC in herbage may have compromised intake on the 20- and 50-MSR treatments.

Concentration of total digestible nutrients and its ratio with crude protein in herbage

Solar radiation treatments influenced ($P < 0{\cdot}01$) the concentration of TDN in herbage except in 2000 (Table 1). The concentration of TDN in herbage was greatest for the 80-MSR treatment while that of the 20- and 50-MSR treatments did not differ. The higher concentration of TDN on the 80-MSR treatment is the consequence of a lower ADF concentration and higher concentrations of TNC in 2001 and 2002. The lack of difference between treatments in TDN concentration in 2000 may be due in part to it being the first year after sward establishment. Isselstein (1993) reported no difference in ADF concentration associated with shading during the seeding year but increases occurred thereafter. Peri *et al.* (2007) reported shade had little effect on the organic matter digestibility of orchardgrass. It could be that changes in concentration of TDN were associated with changes in resource allocation that occurred after vernalisation (Belesky, 2005).

The estimates of TDN concentration indicate that herbage could support average daily liveweight gains of approximately 0·85–1·30 kg hd d^{-1} for growing medium-frame cattle (NRC, 1996). The nutritive value of the herbage, based on TDN concentrations alone, would also meet the energy requirements of lactating and dry beef cows throughout all stages of production provided peak daily milk production did not exceed 4·5 kg (NRC, 1996).

Metabolizable energy (ME), estimated as TDN, allows expression of the ME : CP quotient on a equivalent-unit basis. This quotient provides a means of assessing nutritive value of herbage relative to ME and nitrogen concentrations. Very often, high CP concentrations in herbage are equated with herbage of high quality. However, feeds with ≥200 g CP kg^{-1} DM are often considered as 'protein supplements' (Ensminger *et al.*, 1990). High CP concentrations in herbage may present a dilemma and should be considered in relation to their ME concentration. A TDN : CP ratio of 5·0–7·0 should meet animal and rumen micro-organism needs while allowing for variation in forage system management and seasonal growing conditions (NRC, 1996; Moore *et al.*, 1999). Values <5·0 suggest an excess of herbage N relative to energy. Grazing livestock might avoid forages with TDN : CP values of <5·0 because of low TNC concentrations (Mayland *et al.*, 2000; Smit *et al.*, 2006), or perhaps because excessive N may trigger a chemostatic reduction in intake.

The TDN : CP ratio in herbage was influenced ($P < 0{\cdot}001$) by the solar radiation treatments (Table 1). During all 3 years, the 80-MSR treatment had higher TDN : CP ratios than the 20- and 50-MSR treatments which did not differ from one another. In 2000, the higher TDN : CP ratio on the 80-MSR treatment can be attributed to a lower CP concentration and a greater TNC concentration as the ADF concentration was not influenced by solar radiation treatment. In 2001 and 2002, the 80-MSR treatment had a lower CP concentration, a higher TNC concentration, as well as lower ADF concentration, which is reflected in a greater degree of separation between the 80-MSR treatment compared with the TDN : CP ratio of the 50- and 20-MSR treatments. Lower CP and increased TNC concentrations on the 80-MSR treatment should improve N-use efficiency by livestock.

Across all years and treatments, TDN : CP ratios were extremely low. Values indicate that the herbage will generate high rumen NH_3-N and blood urea nitrogen (BUN) concentrations, resulting in increased urinary N loss. High rumen NH_3-N and low herbage TNC concentrations could reduce intake, and coupled with energy costs for N excretion, may limit animal performance. Neel *et al.* (2003) found performance of livestock was similar on open pastures and silvopastoral systems despite superior ME estimates for silvopasture herbage.

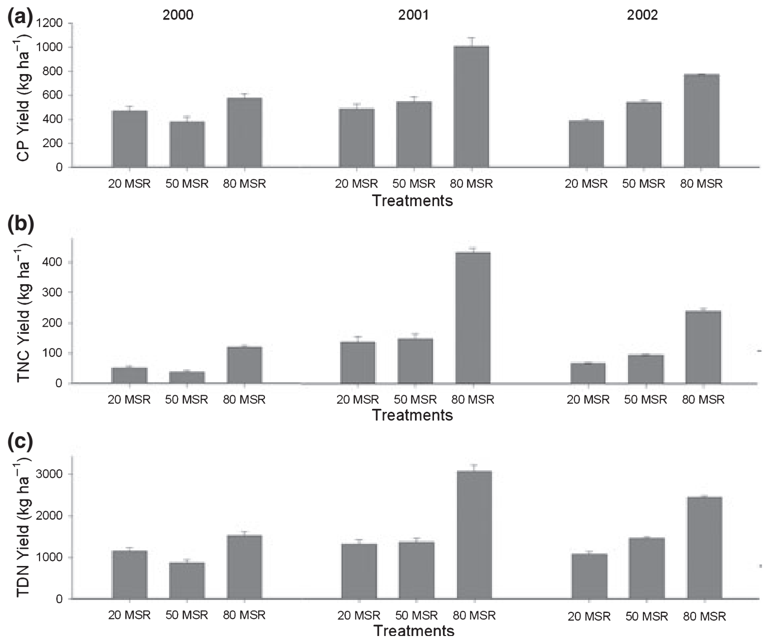

Figure 3 Yields of (a) crude protein (CP), (b) total non-structural carbohydrate (TNC) and (c) total digestible nutrients (TDN) of herbage (kg ha^{-1}) for treatments: 0·80 of maximum solar radiation (MSR-80), 0·50 of maximum solar radiation (MSR-50) and 0·20 of maximum solar radiation (MSR-20) in 2000, 2001 and 2002. Values are means and standard errors of twelve replicates.

Yields of nutrients

Total CP, TNC and TDN yields are presented in Figure 3. CP yield was influenced by MSR treatment ($P < 0{\cdot}01$) in 2001 and 2002. CP yield was greater for treatment 80-MSR in 2001. In 2002, CP yield on treatment 80-MSR was greater than that on the 20- and 50-MSR treatments. As CP concentrations were higher on the 20- and 50-MSR treatments, the greater CP yield on the 80-MSR treatment is a reflection of its superior DM yield.

Yield of TNC was influenced ($P < 0{\cdot}001$) by MSR treatment in all 3 years. In 2000, the higher yield of TNC on the 80-MSR treatment than the 20- and 50-MSR treatments was due to the greater TNC concentration of herbage. In 2001 and 2002, this advantage was a result of superior TNC concentration and DM yield. Higher TNC yield should result in improved N-use efficiency by livestock.

Yield as TDN was influenced (2000: $P < 0{\cdot}05$; 2001 and 2002: $P < 0{\cdot}001$) by MSR treatment. In 2000, as TDN concentrations did not differ between treatments, this is a reflection of the trend for a higher DM yield with decreased shading. Higher TDN yields in 2001 and 2002 on treatment 80-MSR reflect both the superior TDN concentration and DM yield.

Conclusions

Yields of DM and nutrients from herbage were superior for 0·80 of MSR although DM yield was approximately 0·42 of that obtained from a comparable open pasture during 2002. Herbage grown under <0·60 of total solar radiation had greater CP and nitrate concentrations, and lower non-structural carbohydrate concentrations in all 3 years of the study and lower TDN concentrations in the last 2 years of the study. Nitrate concentrations in herbage grown under 0·20 and 0·50 of total solar radiation were high enough to be predicted to impact on animal health and performance if it were the sole source of intake. Higher N-use efficiency by livestock would occur under higher light availability. The high CP concentrations in herbage as a result of appropriate thinning practice in an Appalachian silvopastoral system suggest that the herbage could be utilized as a protein supplement to herbage with low nitrogen and high fibre concentrations. From the results of this study, woodlands should be thinned to allow 0·80 of MSR to reach the understorey sward.

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